

Locomotive Aftertreatment - Project Updates

by

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Projects Covered Today

- * EPA "Tunnel 41" Study
 - » Exhaust temperature extremes in tunnel operation
- * Diesel Oxidation Catalyst
 - » UP2368 – 3,800 HP Line-Haul - Tier 0
- * Diesel Particulate Filters
 - » "California Emissions Program
 - » DPF on two 1,500 HP switcher locomotive

Locomotive Exhaust Temperatures During High Altitude Tunnel Operation in Donner Pass

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Brian Nelson, Brian Olson
U.S. Environmental Protection Agency
Office of Transportation and Air Quality

Michael E. Iden, P.E.
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Nov. 2008



New Locomotive Emission Standards

- March 2007 – EPA proposed new Tier 3 and Tier 4 emissions standards for locomotives and commercial marine engines
- March 2008 – Tier 3 and Tier 4 regulations finalized
 - Implementation of Tier 4 PM and NO_x Standards in 2015
- Tier 4 Locomotive Standards:
 - Will require catalytic exhaust aftertreatment for the first time in this sector
 - 1.3 g/bhp-hr (1.7 g/kw-hr) NO_x
 - Urea SCR
 - 0.03 g/bhp –hr (0.04 g/kW-hr) PM
 - Soot trapping and VOC oxidation



Addressing Stakeholder Concerns Regarding SCR

- SCR catalyst durability over locomotive life
 - Maximum exhaust temperature has dominant impact on catalyst durability
 - Fe-Zeolite SCR durability not significantly impacted for temperatures $<600^{\circ}\text{C}$
 - Fe-Zeolite SCR catalysts gradually degrade in temperatures $\sim 650\text{-}700^{\circ}\text{C}$
 - Initial concerns that post-turbine exhaust temperatures could exceed 700°C during high altitude tunnel conditions



Identifying Operating Conditions

- EPA worked with GE, EMD, UP and BNSF to identify extreme exhaust temperature conditions for locomotive operation
 - Multiple-locomotive consists in heavy-haul operation on mountain grades and through multiple tunnels during summer months
 - Especially the rear-most locomotive positions within the lead consist
 - The Norden tunnel system at Donner Pass was identified as one of the worst case locations with respect to locomotive consist operation
 - Multiple tunnels in quick succession
 - High altitudes and long grades through the tunnels
 - 2-mile long unventilated tunnel (Norden #41) leading up to the summit
 - Oxygen depletion and high temperatures in tunnel
 - Heavy freight trains (8,000 to 14,500 tons of freight per train)



Train Test Route



- 127-mile route from Sparks, NV to Roseville, CA
 - Starting elevation of 4400' climbing to a maximum of 6890' at the west portal of Tunnel #41 near Norden CA
- Data acquisition focused on the 50 mile west-bound climb through Donner Pass in the Sierra Nevada Mountains



Tested Locomotives

- UP8353
 - EMD SD70ACe Locomotive
 - EMD 16-710G3C-T2
 - 3200 kW traction power
 - Tier 2 emissions
- BNSF7736
 - GE ES44DC Locomotive
 - GE GEVO V12
 - 3200 kW traction power
 - Tier 2 emissions



Data Acquisition

- Ambient Air:
 - Temperature (above cab)
 - Relative humidity
 - Barometric pressure
 - NOx concentration
 - Oxygen (O₂) concentration
- Engine/Locomotive:
 - Exhaust temperature @ exhaust turbine inlet
 - Exhaust temperature @ exhaust turbine outlet (stack)
 - Radiator inlet air temperature
 - Radiator outlet air temperature
 - Engine speed
 - Exhaust NOx concentration
 - Exhaust O₂ concentration
 - Air temperature @ turbo-compressor inlet (air filter cabinet)
 - Air temperature inside locomotive auxiliary cab
- Infrared thermographic measurements of external surfaces
- Proprietary EMS data provided by the locomotive manufacturers



Locomotive Consist Arrangement



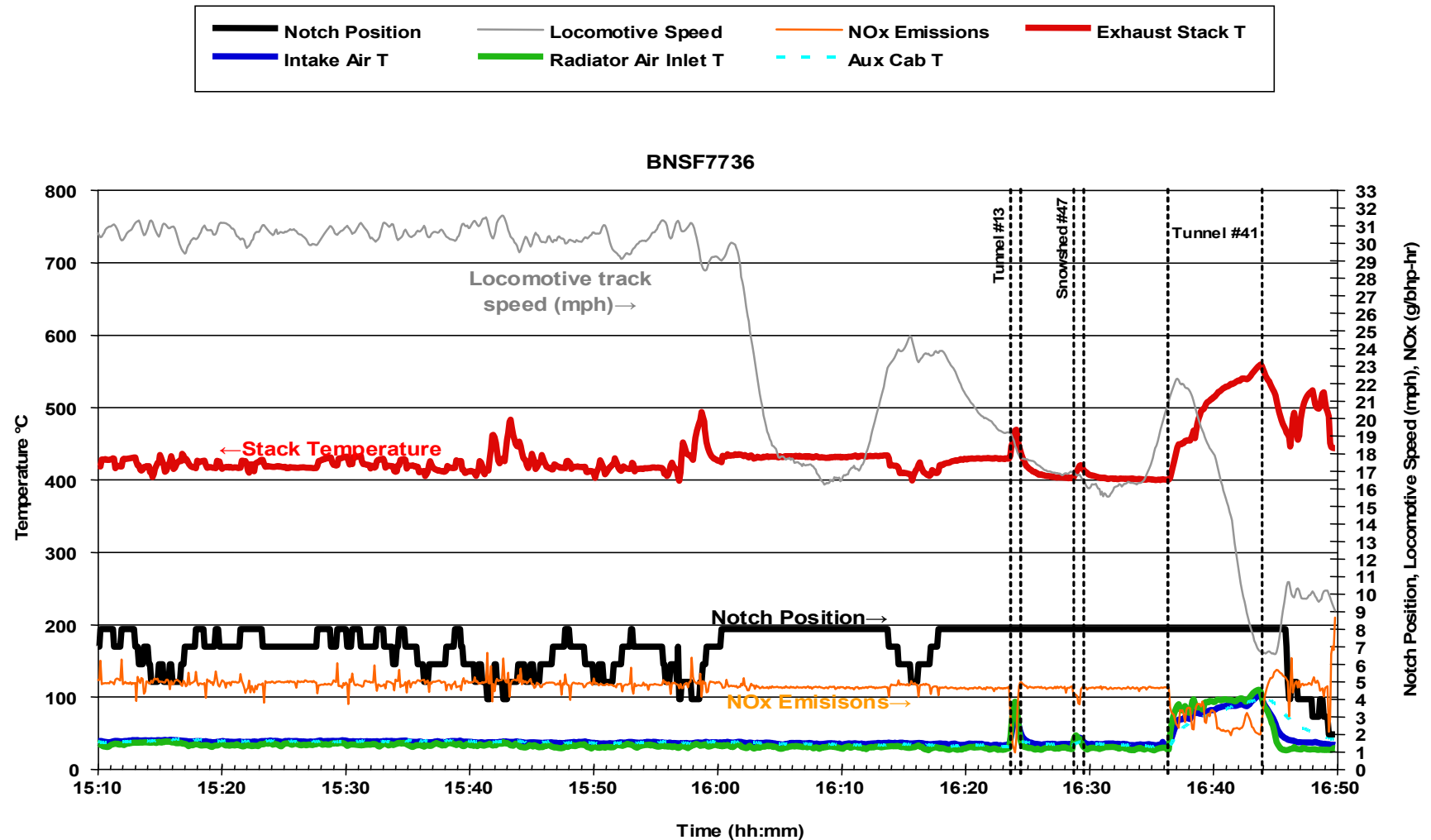
Direction of travel

- 62-car freight train
- 8,347 tons
- 5th locomotive at rear of train (distributed power)



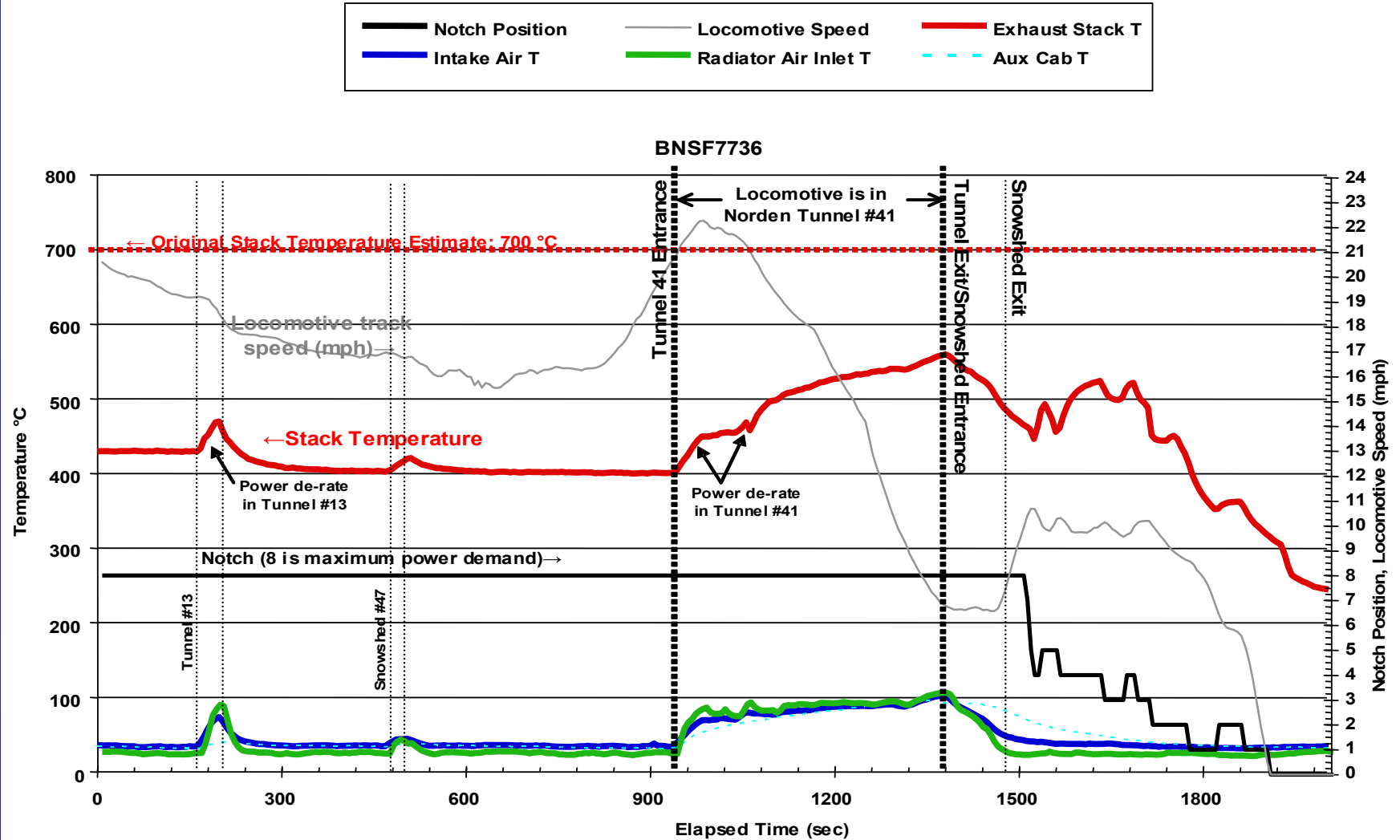
Tunnel Testing to Validate Catalyst Durability

Tier 2 GE locomotive tested at a high-altitude & through multiple tunnels (Donner Pass Norden Tunnel System)



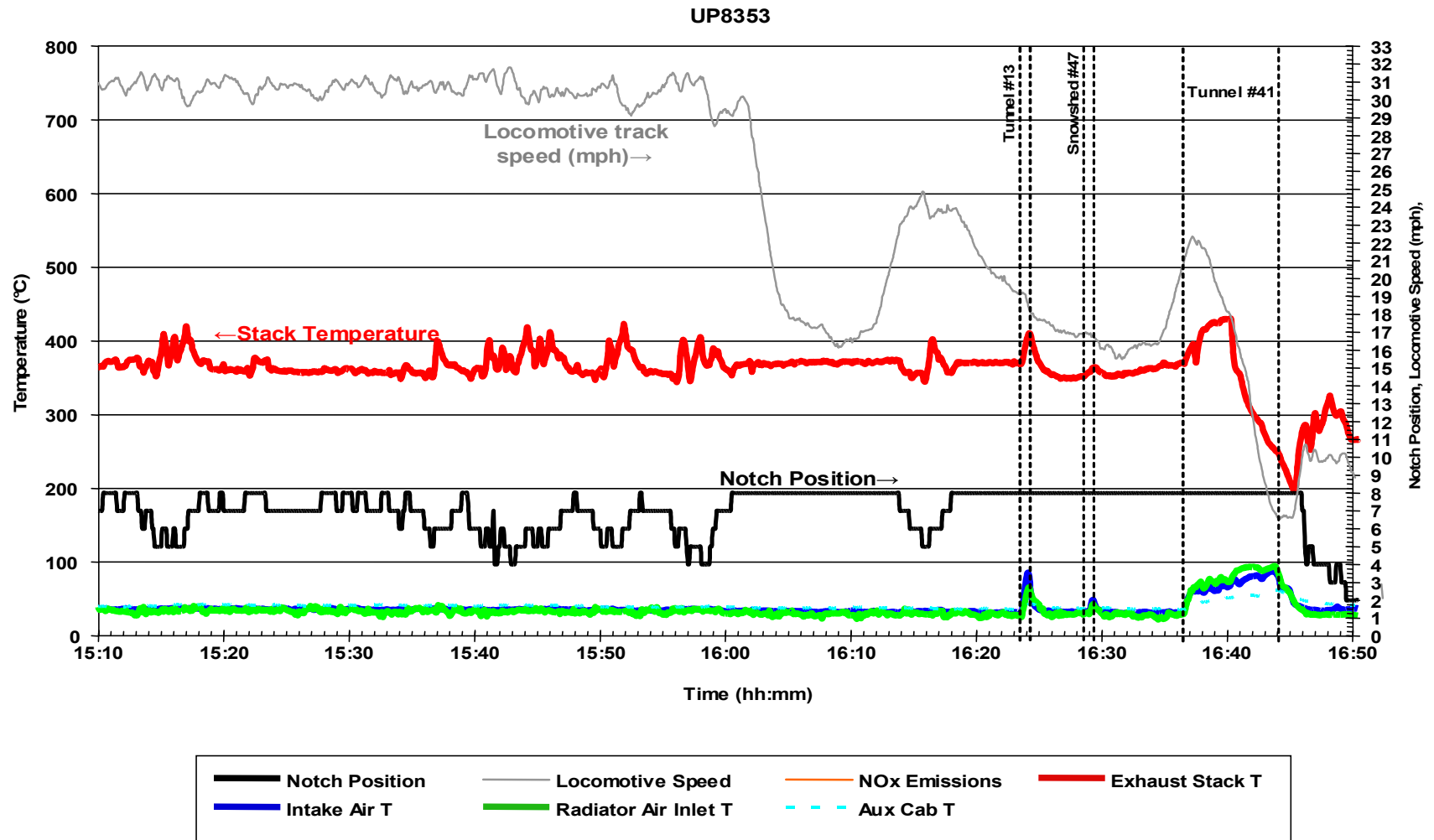
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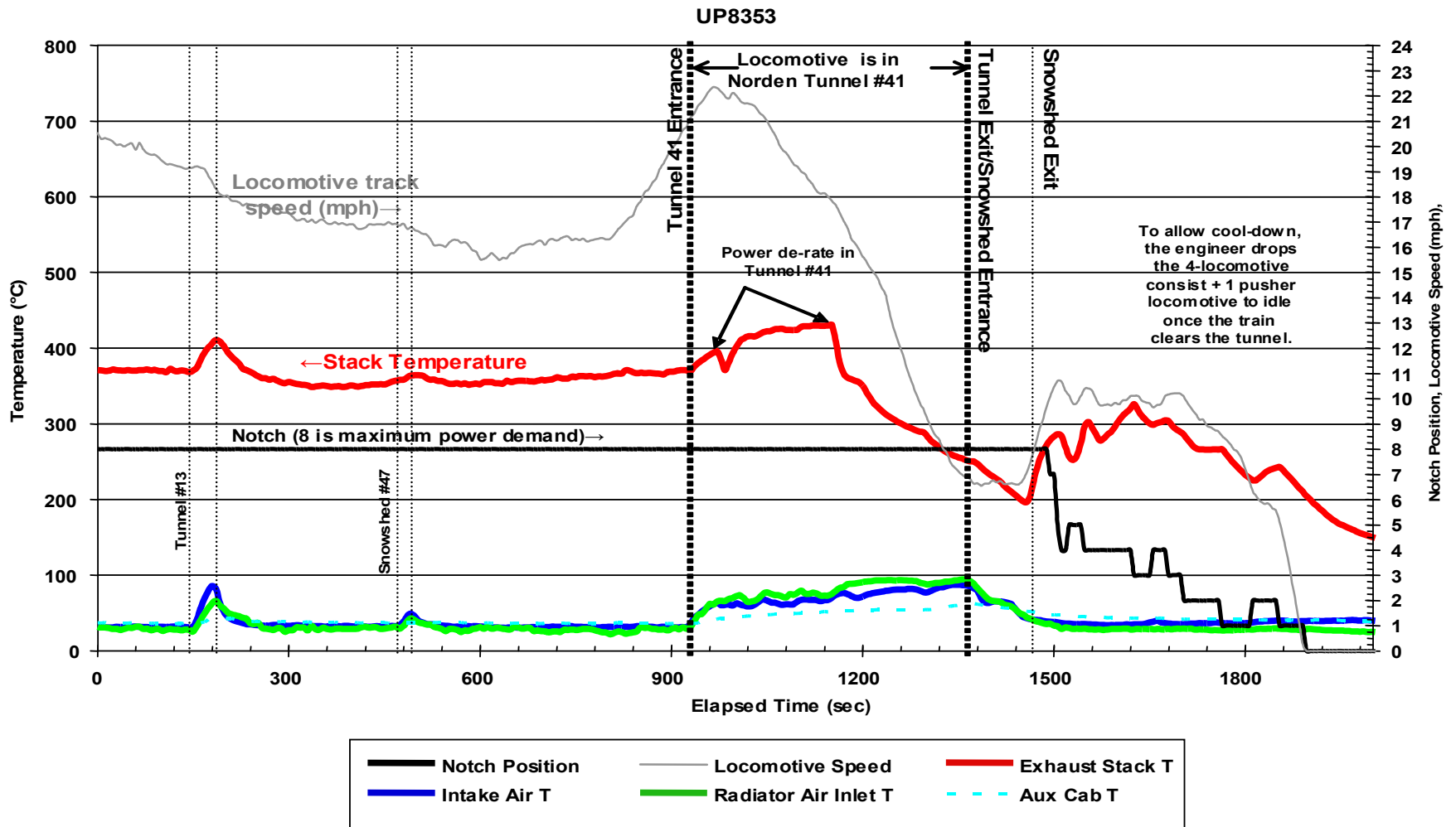
Tunnel Testing to Validate Catalyst Durability

Tier 2 EMD locomotive tested at a high-altitude & through multiple tunnels
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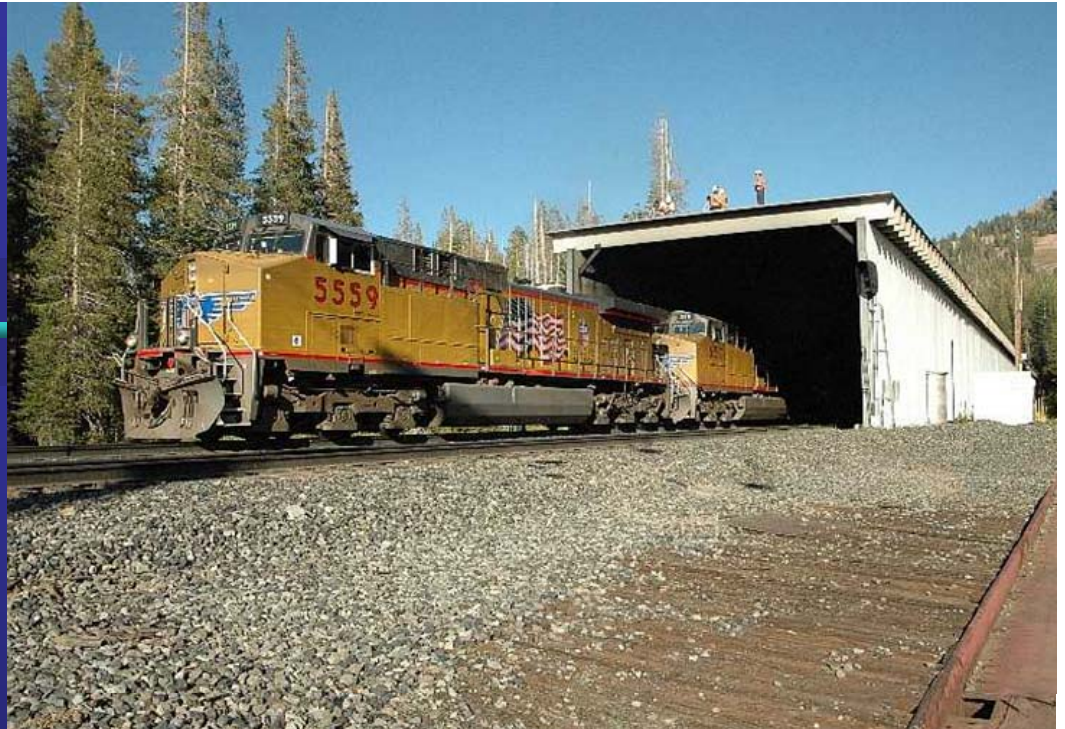
Tunnel Testing to Validate Catalyst Durability

Tier 2 EMD locomotive tested at a high-altitude & through multiple tunnels (Donner Pass Norden Tunnel System)



Tunnel #41 West Portal

- Significant power de-rate occurred just prior to and within Tunnel #41
- Multiple temperature-limit “alarms” had been reached
- Train was stopped to allow high-idle cool-down when clear of the tunnel
 - Ensured availability of locomotive dynamic braking for the “downhill” portion of the route



Conclusions

- Maximum exhaust temperature was well below safety margin for catalysts
 - Maximum exhaust temperatures under extreme conditions are self-limiting due to engine protection measures taken by the engine management system
 - Operating at the highest temperature extremes in Norden Tunnel #41 resulted in peak exhaust stack temperatures of 560 °C
 - Well below the temperature where significant thermal degradation would be expected
- The Donner Pass locomotive field study provided key operational data inputs for use within a subsequent EPA accelerated catalyst thermal degradation study



For More Information

Proceedings of the ASME Internal Combustion Engine Division 2008 Spring Technical Conference
ICES2008
April 27-30, 2008, Chicago, Illinois, USA

ICES2008-1625

LOCOMOTIVE EXHAUST TEMPERATURES DURING HIGH ALTITUDE TUNNEL OPERATION IN DONNER PASS

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U.S. EPA
Office of Transportation and Air
Quality

Brian Nelson
U.S. EPA
Office of Transportation and Air
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Brian Olson
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Acknowledgments & Contact Info

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- General Electric Transportation Systems
- Electro-Motive Diesel

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EXHAUST EMISSIONS FROM A 3,800 hp EMD SD60M LOCOMOTIVE EQUIPPED WITH A DIESEL OXIDATION CATALYST

by

Dustin Osborne and Steven Fritz
Southwest Research Institute®

Mike Iden
Union Pacific Railroad Company



BUILDING AMERICA™



Acknowledgements

- * **SwRI performed this project in cooperation with MIRATECH Corporation, Union Pacific Railroad Company, and U.S. EPA.**

- * **Initial Testing Funded by the U.S. EPA – Office of Transportation and Air Quality Assessment and Standards Division- National Vehicle and Fuel Emissions Laboratory- Ann Arbor, Michigan**
 - » **EPA Contract No. EP-C-05-018**

- * **Subsequent Testing and Monitoring Funded by Union Pacific Railroad Company**

- * **Catalyst design/manufacture provided by MIRATECH Corporation**

- * **Installation, Testing and Monitoring Conducted by Southwest Research Institute**



EMD SD60 Locomotive

- ★ **This Project consists of the retrofit of an experimental Diesel Oxidation Catalyst (DOC) to a Tier 0 Line-haul EMD SD60 locomotive.**
 - » **First such retrofit to a high HP freight locomotive in the U.S.**

Locomotive Number	UP 2368
Locomotive Model	EMD SD60M
Original Build Date	1989
Rebuilt to Tier 0	April 2006
ZTR Smart Start installed	April 2006
Engine Model	EMD 16-710-G3A
Rated Traction Power	3800 hp
Displacement/Cylinder	710 in ³
Compression ratio	16.0:1
Rated engine speed	904 rpm
Fuel Injection	Mechanical Unit Injectors



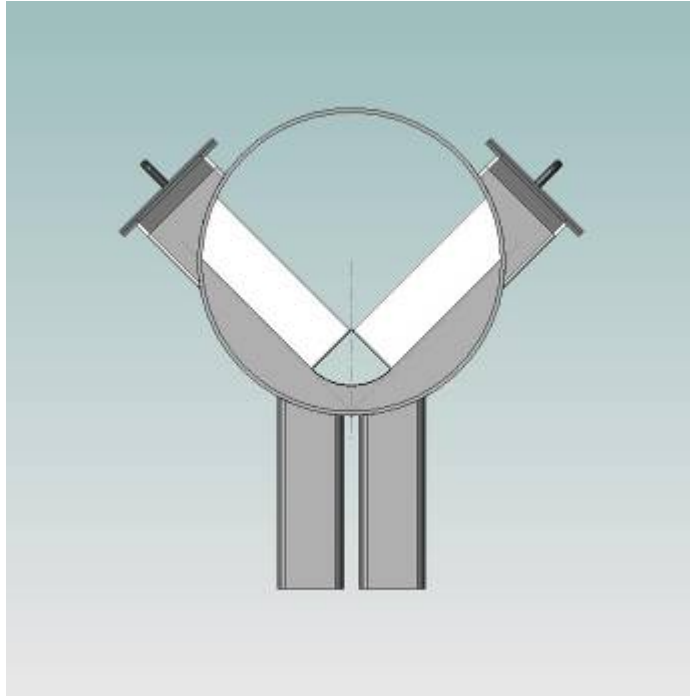
“The Curse of the Test Locomotive”



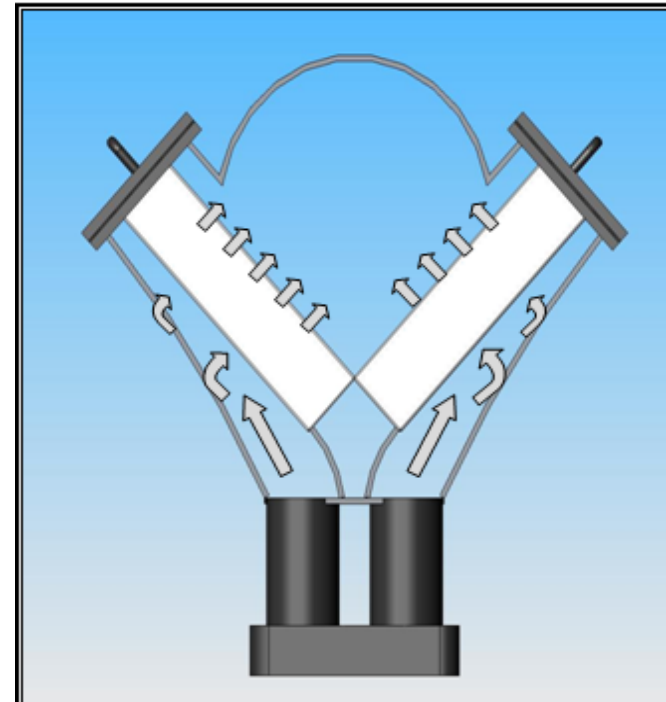
- * Original test locomotive = UP2448
- * Involved in derailment in San Timoteo Canyon near Redlands, Calif. on August 26, 2006.
- * UP identified replacement
 - » Tier 0 - EMD SD60 UP2368



In-Manifold DOC Design



First Attempt
“breathing” limitations



Gen 2 Design

Pre-Turbine DOC on an EMD SD60



**Power Assembly Service
Access Remains**

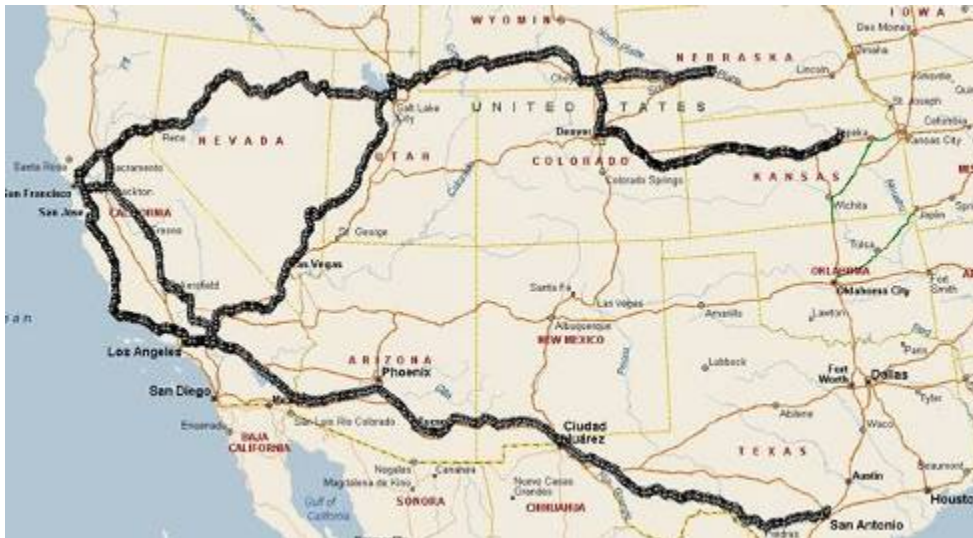


With Roof off of locomotive

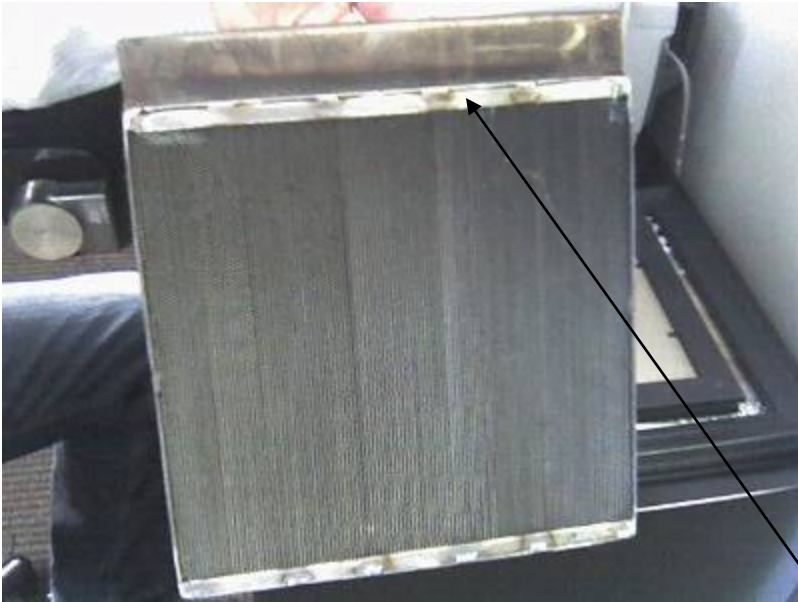
On-Board Datalogger



- * UP2368 instrumented with data logging system
- * Continually monitors and records operational parameters during revenue service
- * Cellular phone package used to monitor and download data via internet
- * GPS equipped to track movement



Gen 2 Durability



- * UP 2368 entered revenue service in October 2006
- * Three-month Inspection revealed a minor mechanical problem with the catalyst elements that was quickly repaired
 - » Catalyst was Clean and Dry
- * Locomotive Returned to SwRI in April'07 for Second Inspection and Six-month Emissions Test
 - » Catalyst was Clean and Dry
 - » However, mechanical failures of catalyst frame
 - » Pulled all oxycat elements, returned loco to service w/o elements
 - » Miratech redesigned catalyst frame, and reinstalled at Los Angeles in June'07.

For More Information

Proceedings of JRCICE2007
2007 ASME/IEEE Joint Rail Conference & Internal Combustion Engine Spring Technical Conference
March 13-16, 2007, Pueblo, Colorado, USA

JRCICE2007-40060

**EXHAUST EMISSIONS FROM A 2,850 kW EMD SD60M LOCOMOTIVE EQUIPPED WITH A DIESEL
OXIDATION CATALYST**

Dustin T. Osborne and Steven G. Fritz
Southwest Research Institute

Mike Iden
Union Pacific Railroad Company

Don Newburry
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www.ASME.org

Last Symposium - Late Breaking News

- * Replacement DOC elements installed in LA in JUN'07
 - » 1,163 hours on new elements as of 07-OCT-2007
- * 08-OCT-2007
 - » UP in West Colton reported low power
 - » Shop contacted Mike Iden per sticker instructions



**THIS ENGINE EQUIPPED WITH EXPERIMENTAL
CATALYSTS IN EXHAUST MANIFOLDS.
DO NOT REMOVE MANIFOLDS OR PERFORM
ANY MAINTENANCE ON MANIFOLDS WITHOUT
FIRST CONTACTING:**

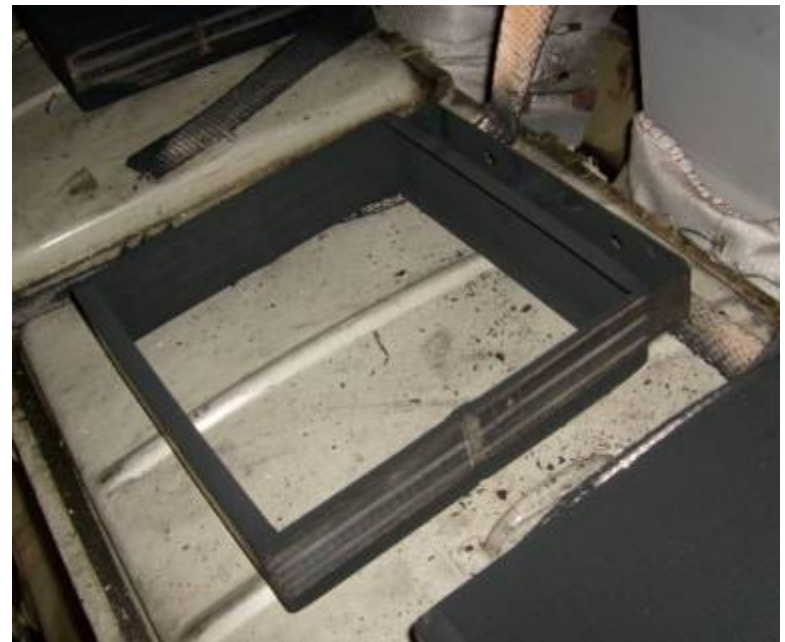
**M. E. IDEN
UNION PACIFIC RAILROAD
708-**



BUILDING AMERICASM

Another Iteration on Catalyst Elements

- * UPRR inspection in Oct-07 revealed turbo screen plugged with DOC debris
- * Miratech field service dispatched to inspect & remove DOC elements
 - » 2 of 16 catalyst elements damaged
- * All 16 catalyst elements removed and sent to Miratech for failure analysis
 - » Locomotive continued to operate in revenue service w/o DOC elements.
- * Miratech developed V-Cat design

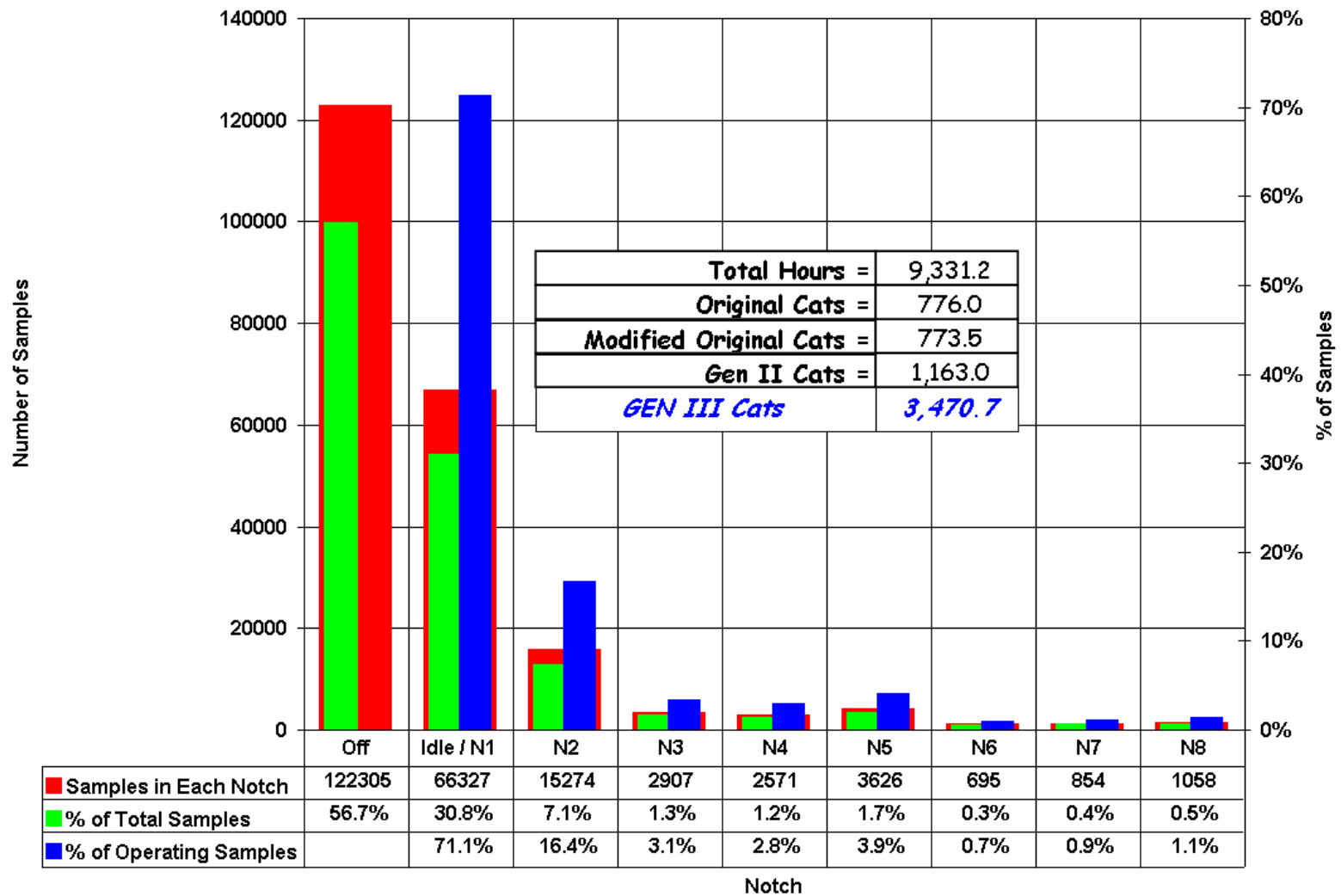


UP2368 – V-Cat Testing

- * Redesign to V-Cat delivered to SwRI May 2008
- * Re-baseline with stock exhaust manifold
- * Install V-Cat, degreen, run 0-hour test

		Freight Cycle			
		HC	CO	NOx	PM
Date		g/hp-hr	g/hp-hr	g/hp-hr	g/hp-hr
23-May-08	Re-baseline, ULSD	0.41	0.48	8.5	0.27
29-May-08	V-Cat + ULSD	0.18	0.11	8.2	0.14
26-Dec-08	V-Cat + ULSD + 6-months	0.15	0.11	7.8	0.17
V-Cat vs Re-Baseline, % change		-57%	-78%	-3%	-46%
V-Cat @ 6-months vs Baseline, %		-65%	-77%	-9%	-35%
V-Cat @ 6-months vs 0-Months, %		-19%	6%	-6%	20%

UP2368 Duty-Cycle & Hour Summary



As of May 31, 2009

Additional V-Cat Applications

▶▶ Passenger Locomotive Installations

– VIA Rail

- EMD F40PH - 16-645 (3,000 Hp)
- Demonstration started - 4/08
- ~ 4,000 hrs



– West Coast Express

- EMD F59PH – 12-710 (3,000 Hp)
- Demonstration started - 11/08



V-Cat Marine Application

Ingram Barge – M/V Gale C



Length 200 feet - Width 50 feet - Triple Screw GM 12-710G-7B 9180 HP
Built 1973 by St. Louis Ship, St. Louis, MO
Repowered 1999

- * 3 x 3,000 HP EMD 12-710G engines
- * Miratech V-Cat installed April 2009 on center engine
- * Currently at ~1,000 hours – no noticeable change in engine parameters
- * First inspection due in September, 2009

Experimental Application of Diesel Particulate Filters to EMD Switcher Locomotives



Background - CEP

- * CEP = California Emissions Program
- * Part of CARB diesel toxics reduction program
- * CARB looked for a voluntary PM reduction effort from the railroad industry in lieu of greater use of CARB diesel fuel
 - » Funded by BNSF & UP railroads
 - \$5M budget
 - » Scope:
 - PM reduction
 - Switchers
 - California
- * CARB interest in a Diesel Particulate Filter (DPF) installed and functioning on a switcher locomotive(s) in California
- * Project Managed by TTCl in Pueblo CO.



1,500 hp EMD MP15DC Switcher Locomotive

Phase 1 – Laboratory Screening

- Task 1: Install EMD 16-645E locomotive engine
- Task 2: Reduce lubricating oil consumption
- Task 3: Screen candidate DPF and Oxidation Catalyst systems on test engine
 - | Evaluated 13 different DOC and DPF systems
 - | Selected top 3 for 500-hour initial durability test
 - | Selected best performer for Phase 2 field implementation
- » Results of testing showed that a DPF with a diesel burner offered best trade-off for this application
- » Additional details about Phase 1 can be found at:
 - ASME ICE2003-549 & ICEF2003-707
 - CIMAC 2004 – Paper #70
 - <http://www.arb.ca.gov/railyard/ryagreement/071306fritz.pdf>

Phase 2 – Field Implementation



BNSF3703

- Released from overhaul on June 2006
- Equipped with idle reduction system & APU

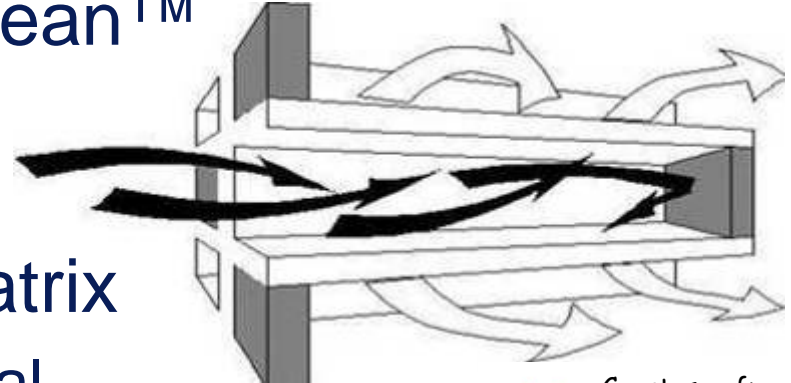
UPY1378

- Overhauled in Fall 2005
- Routed to SwRI in Feb. 2006 for DPF mounting design concept meeting
- Equipped with idle reduction system



DPF Selected for Demonstration

- * DPF selected was a MobiClean™
 - » Wall flow filter
 - » High efficiency
- * Each DPF has 3X4 brick matrix
 - » Extended maintenance interval

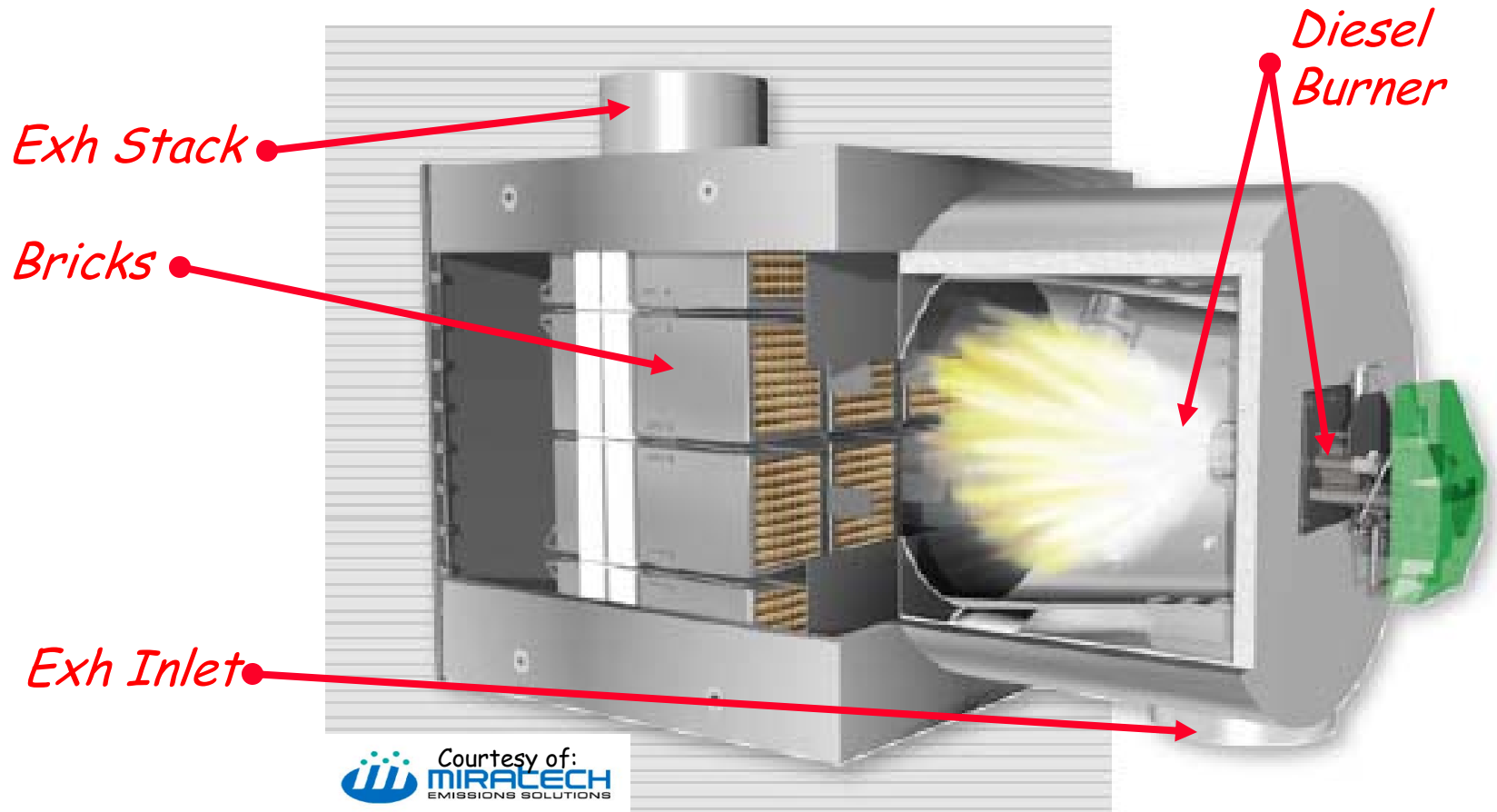


Courtesy of:
MIRATECH
EMISSIONS SOLUTIONS



DPF Selected for Demonstration

- * MobiClean™ DPF has diesel burner
 - » Needed to provide adequate temperature for regeneration of DPF



CEP Phase 2 – More Information

Proceedings of ICEF 2007
2007 Fall Technical Conference of the Internal Combustion Engine Division
Charleston, SC. October, 2007

ICEF2007-1626

Experimental Application of Diesel Particulate Filters to EMD Switcher Locomotives

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DPF Demonstration Locomotives



Locomotive	UPY1378	BNSF3703
Date into Service with DPF	Oct. 2006	April 2008
Months in Revenue Service with DPF	32	11
DPF Running Hours	5,766 (as of May 27, 2009)	3,219 1,624 Total In Calif. 4/08 – 3/09

<u>UPY1378 Summary Sheet</u>				Estimated total hours of operation = 5,765.9 Hours								
Samples in Each Notch				241,681	43,797	4,768	5,137	1,434	1,070	376	350	727
% of Total Samples				80.7%	14.6%	1.6%	1.7%	0.5%	0.4%	0.1%	0.1%	0.2%
% of Operating Samples					76.0%	8.3%	8.9%	2.5%	1.9%	0.7%	0.6%	1.3%
				Off	Idle / N1	N2	N3	N4	N5	N6	N7	N8

Issues encountered during demo:

- » DPFs are heavy ~ 1,140 pounds each x 2 per locomotive
- » Trapping Efficiency is below desired levels
 - Initial efficiency ~ 80%
 - Expected 90 to 95% efficiency
 - | Tried DOC upstream of DPF to reduce VOF
 - | New filter material with reduced porosity
 - | New housing design to reduce thermal growth / distortion
- » White smoke @ regeneration after extended Idle
 - Caused by oil and fuel build up on “dirty” side of filter
 - Burning off of oil & fuel causes white smoke
 - Reduce by:
 - | More frequent regenerations of DPF
 - | Lower oil consumption rings and liners
 - | High reliability of ignition of the burner
 - | High initial temperatures at the face of the DPF at start of regen cycle
- » Burner ignition reliability
 - Problem addressed effectively by Hug

BNSF 3703 Update

- * Visual inspection by SwRI in March, 2009 at BNSF Hobart Yard in Commerce, CA
 - » Noted DPF element dislodged in Right DPF
- * BNSF dragged BNSF3703 from Commerce to San Antonio
 - » Detailed inspection performed by SwRI & Miratech
 - » Miratech declared both DPF units to be unrepairable

BNSF 3703 Right DPF



April 2009

BNSF3703 – Exhaust Leak Through DPF Housing – Right DPF



April 2009

CEP Status – June 2009

- * UPY1378 continues to operate in Roseville
- * BNSF3703 in San Antonio
 - » Discussions with BNSF, TTCI, CARB, Miratech as to how to proceed.

